63-3-2

401 900

KRYPTON FILLED THERMIONIC CONVERTER

PARMA RESEARCH LABORATORY
UNION CARBIDE CORPORATION

QUARTERLY TECHNICAL PROGRESS REPORT NO. 1

Jan. 1, 1963 - March 31, 1963

CONTRACT NO. AF33(657)-10132

April 1963

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This report was initiated by the Flight Accessories Laboratories, Air Force Systems Command. The research work on which this report is based was accomplished by the Parma Research Laboratory, Union Carbide Corporation, P. O. Box 6116, Cleveland 1, Ohio, under Air Force Contract AF 33(657)-10132 entitled "Krypton Filled Thermionic Converter."

The report was written by R. Forman, Project Leader. The following scientists, engineers and technicians have contributed to this project: J. A. Ghormley, Group Leader; F. W. Meszaros and J. A. Raley.

Mr. A. E. Wallis monitored the project for the Flight Accessories Laboratories of the Air Force Systems Command.

ABSTRACT

Research work on irradiated inert gas thermionic diodes for the first quarter of 1963, under contract AF 33(657)-10132, [Task 817305-26] is presented. Tubes containing argon and krypton at various pressures in the range of about 100 torr were tested in the unirradiated condition and under high radiation conditions, including Co^{60} gamma irradiation and the radiation from the core of a 5 megawatt swimming pool type reactor. The results of these measurements are described and evaluated. Measurements on inert gas filled irradiated diodes with negative resistance characteristics are also discussed showing how such diodes can be used as a.c. generators over a range of frequencies up to 10 megacycles.

1.0 INTRODUCTION

For the last three years the Union Carbide Corporation has been engaged in a research program to study electron propagation through high pressure inert gas filled diodes. These measurements have been made with the gas both in the ionized and unionized state. The results of these studies have shown: (1) an inert gas filled thermionic converter, in which the space charge is neutralized by positive ions produced in the gas by nuclear radiation, seems feasible, and (2) inert gas filled thermionic diodes or converters can be designed to have negative resistance characteristics which could be used for obtaining a.c. outputs.

Government sponsorship of this continuing program at Union Carbide starts at a time when two principle objectives are being actively pursued. They are: (1) experiments designed to learn how to increase power output and how to decrease plasma resistance between cathode and anode in an irradiated inert gas diode, and (2) studies on irradiated inert diodes having negative resistance characteristics to determine quantitatively the mechanism of operation and means for increasing negative resistance effects.

2.0 BACKGROUND

Early studies[1] in high pressure (1-300 torr) rare gas filled diodes using a thermionic cathode showed that high temperature filament operation (2500-3000°K) in the gases xenon, krypton and argon led to violations of space charge conditions. This phenomenon was explained by showing that the fractional ionization of the heavier inert gases at these elevated temperatures was apparently sufficient to partly neutralize space charge effects. In order to verify this explanation by other experiments, it was thought necessary to show that similar effects, associated with space charge neutralization, could be obtained if ions were produced in the rare gas ambient of the diode by radioactive means rather than thermal means. The initial experiments[2] employed fission product krypton as the gas in a high pressure thermionic diode. Fission product krypton contains about 5 per cent Kr^{85}, which is nearly a pure beta emitter with a half life of 10.5 years. This choice permits one to make a high pressure gas diode, containing krypton, with a built-in radiation source. The results of these experiments seemed to verify the initial

speculation about the effect of ions on the current-voltage characteristics of inert gas filled diodes. In addition it was found that under certain conditions of pressure and spacing the diodes, containing fission product krypton, showed negative resistance characteristics.

The next series of experiments was designed to obtain a better understanding of the phenomena associated with irradiated inert gas diodes. This study was made to determine how the current-voltage characteristics of the irradiated gas filled diodes varied with the following parameters: (a) type of inert gas, (b) pressure of gas, (c) geometry of diode (planar or cylindrical), and (d) radiation dosage. The results of these studies, made on diodes filled with natural gas and irradiated with either gamma rays from a Co^{60} source or high energy electrons from a Van De Graaff generator were published in 1962[3]. They showed that: (1) only the inert gases xenon, krypton and argon caused negative resistance effects and (2) increased current outputs, at a constant applied anode voltage, were obtained with increasing radiation dosage.

As a consequence of these studies it was felt that it would be feasible to develop a high pressure irradiated inert gas filled thermionic converter. Such a device has a number of possible advantages over a cesium filled thermionic converter. These are:

(a) Low temperature operation is attainable because neutralization of space charge is not dependent on thermal ionization.

(b) The use of inert gas ambient eliminates the corrosion problems associated with cesium vapor.

(c) The negative resistance characteristics associated with high pressure irradiated inert gas thermionic converters suggest that this device can be used to convert heat directly to a.c. electricity.

In order to determine the practical problems associated with such a device it was felt necessary to do further experimental studies in very high radiation environments such as a nuclear reactor. This program was initiated by the testing of diodes in the core of the Union Carbide Test Reactor in Sterling Forest, New York. This reactor is a 5 megawatt swimming pool type reactor with a maximum flux density in the range of 5×10^{13} neutrons/cm^2 sec. These

measurements made on filamentary tubes as well as indirectly heated cathodes confirmed that as radiation dosage was further increased, output current increased.

3.0 DESCRIPTION AND RESULTS OF REACTOR ENVIRONMENT EXPERIMENTS

The general features of the type of diode being used in these studies is shown in Figure 1. It is an indirectly heated type cathode tube employing a Philips impregnated cathode (obtained from Philips Metalonics) which normally operates at about 1100°C and has a work function of 2.1 ev. The cathode is heated by a tungsten filament shown as 1. The cathode consists of a molybdenum body, 2, partially encased in the active impregnated tungsten cylindrical sleeve shown as 3. Surface 3, the electron emitting area, is 0.350" in diameter and 0.5 inch long. Separating cathode 3 and molybdenum anode 7 are lucalox spacers 4 and 5. These spacers are 0.01" thick and the inner surface of both spacers is serrated as shown. The cathode-anode space containing the gas ambient is shown as 6. To prevent the top spacer from falling out when the tube is inverted, a molybdenum cap 8 is mounted on the anode 7 and held to it by screw 9. The entire diode structure is mounted on a glass press shown as 10. From the glass press 10, one goes by means of a graded seal to a quartz envelope.

A photograph of the structure is shown in Figure 2. This diode has a cathode-anode spacing of 1 mm. The hole in the anode is a sight hole for measuring cathode temperature. A top view of the diode is shown in Figure 3. The contact between the top lucalox and the cathode can be seen in this photograph. A bottom view of the tube is seen in Figure 4, which illustrates the method of mounting the filament structure.

Six tubes identical to those illustrated in Figure 2 (1 mm cathode-anode spacing) were processed on an ultrahigh vacuum system such as described in Figure 2 of reference 1. Each tube was filled with a different pressure of gas from 58-430 torr. Two of the tubes filled with 200 torr of argon had small concentrations of Xe (about 0.5 per cent and 5 per cent) added to the argon. The purpose of this latter filling was to see the effect of a slight contamination of Xe on the current-voltage characteristics of an argon filled diode. After preparation, the tubes were tested before irradiation, in the gamma ray environment of a Co^{60}

source and in the core of the swimming pool reactor. A typical result obtained is that shown in Figure 5 for tube 45 D with an argon pressure of 58 torr. Curve a is the current voltage characteristic of the unirradiated diode. Curve b is the case of gamma ray irradiation at a dosage of 1.2 megarads/hr. Curve c is the result when the tube is placed in the core at a flux density of 10^{12} neutrons/cm^2 sec. Figure 6 illustrates the results on the current-voltage characteristics of the same tube when higher flux densities were attained. Curves a, b, c and d are respectively at flux densities of 5×10^{12}, 10^{13}, 2.5×10^{13} and 5×10^{13} neutrons/cm^2 sec. Notice that at lower radiation dosages the current seems to increase approximately as the square root of the radiation intensity. However this effect was not followed in going from a flux density of 2.5×10^{13} to 5×10^{13}. In fact, it was found, at 5×10^{13} flux, that the current output increased with time. This is illustrated in Figure 7 and is based on data from the same tube. There was an appreciable increase in current output in a short time and this seemed to saturate in about a half hour. It is felt that this effect can be attributed to the build-up of gammas from the low lifetime fission products in the reaction.

As a result of these measurements, we concluded:

(1) Maximum saturated current densities in the range of 0.1 - 0.2 amp/cm^2 were obtained from the diodes in the argon pressure range 60-100 torr.

(2) The addition of small concentrations of xenon to argon appeared to cause early breakdown effects (similar to Penning effect), but seemed to have no other significant effect on the general characteristics of the tube.

Measurements were also made on diodes similar to those illustrated in Figures 1-4 under conditions where the anode-cathode spacings were varied. The three diodes tested had a filling of 146 torr of krypton and had a cathode-anode spacing which was respectively 1 mm, 3 mm and 7.5 mm. The results of these measurements are illustrated in Figure 8, which shows the current-voltage characteristics of these three tubes at a flux density of 10^{13} neutrons/cm^2 sec. Curves a, b, and c are for diodes whose respective cathode-anode spacings are 1 mm, 3 mm and 7.5 mm. Surprisingly, in these inert gas filled irradiated diodes the output seems to be almost independent of cathode-anode spacing. This would give unique advantages to a thermionic converter device.

4.0 STUDIES ON IRRADIATED INERT GAS DIODES AS A.C. GENERATORS

These studies have been carried out on fission product krypton diodes similar to that illustrated in Figure 9. The particular tube under study contains a 0.01 inch diameter thoriated tungsten filament, 3.5 cm long, and a one centimeter diameter tantalum anode, 1.25 cm long. The filling gas is about 1.5 curies of Kr^{85} in 150 cc of fission product krypton at 100 torr pressure. The simple circuit used in these measurements is shown in Figure 10(a). The filamentary cathode 1 is heated by a d.c. battery source V_f. The filament current, read by the ammeter A, is varied by resistors $R_f{}^1$ and $R_f{}^2$ and controls the filament temperature. The anode shown as 2 is in series with a tank circuit, consisting of an inductance L_p in parallel with a capacitance C_p, and a d.c. source V_p. By adjusting the voltage V_p, one can adjust the d.c. operating point of the tube so that it falls on the negative resistance portion of the characteristic. When this is done it is found that by the proper choice of inductance L_p and capacitance C_p, one can use the fission product krypton diode as an oscillator and control its frequency from 50 cycles/sec up to 10 megacycles. If one considers the equivalent circuit for the negative resistance diode as a negative resistance, one obtains the simple circuit shown in Figure 10(b). The analysis of this equivalent dynatron circuit[4] leads to the following solution for the current in any branch of the equivalent circuit 10(b):

$$I = A \sin \omega t \exp - {}^1/_2 \ \{r/L + 1/\rho C\} \qquad (1)$$

in which A is a constant and the angular frequency ω is given by

$$\omega = \sqrt{\frac{r+\rho}{\rho} \ \frac{1}{LC} - \frac{1}{4} \left(\frac{1}{\rho C} + \frac{r}{L}\right)^2} \qquad (2)$$

Equation (1) shows the two conditions for oscillation are (a) ρ is negative and (b)

$$\left| \frac{1}{\rho C} \right| \geq \frac{r}{L} \qquad (3)$$

All these quantities can be measured and equation (3) can be verified quite easily by experiment.

A typical example to illustrate the point is that the circuit in Figure 9(a) started oscillating at 416,985 cycles/sec (measured with a Beckman Universal

Eput and Timer Model 7360) when the inductance was 40.2 microhenries, the capacity was 3.62×10^{-9} farads and the resistance of the choke was 1.225 ohms. These values vary measured with a Boonton Q meter Type 260-A. The negative resistance was estimated to be about -10,000 ohms from the static characteristic. Using these values one finds that:

$$\frac{1}{\rho C} \approx \frac{r}{L} \tag{4}$$

Under these conditions the computed frequency is given by

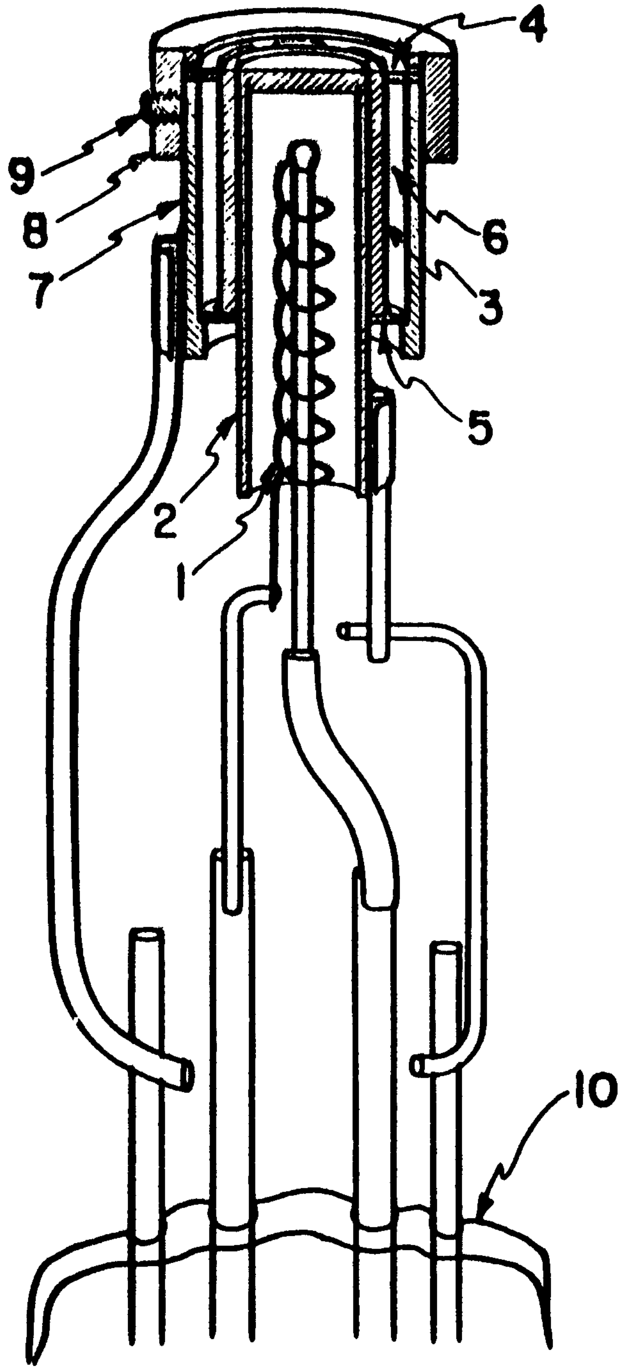
$$f = \frac{1}{2\pi}\sqrt{\frac{1}{40.2 \times 3.62 \times 10^{-15}}} \tag{5}$$

$$= 417{,}000 \text{ cycles/sec.}$$

Studies on this type of tube as an oscillator are continuing. It is puzzling to find that these tubes oscillate in the range of 10 megacycles when the gas pressure between anode and cathode is 100 torr and the anode-cathode space is 0.5 cm. It would seem that the transit time for electrons would be much longer than 10^{-7} seconds under these conditions and so prevent the tube from oscillating at such high frequencies. Our investigations are directed to a further understanding of this phenomenon.

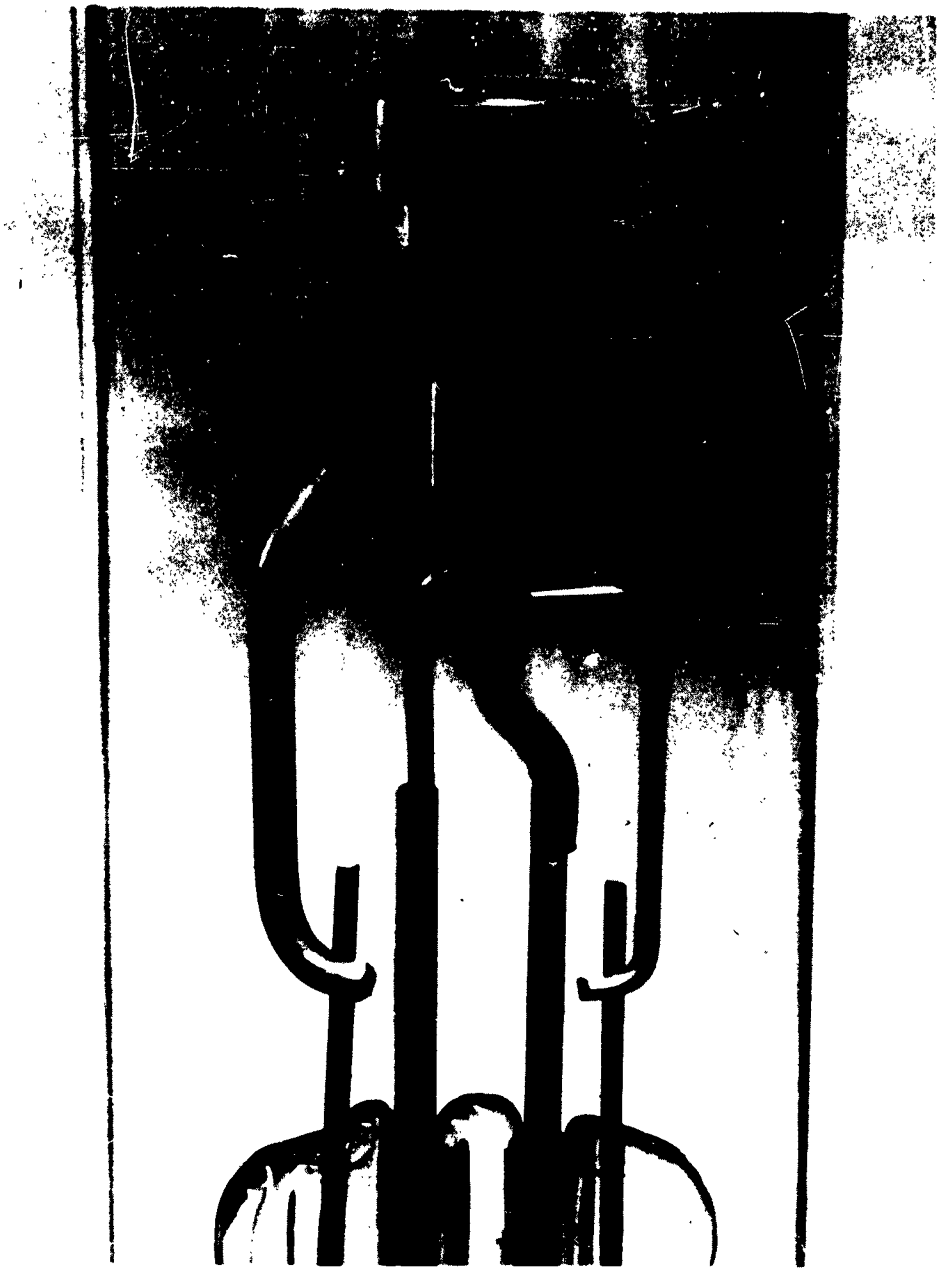
REFERENCES

1. R. Forman, J. Appl. Phys. 32, 1651 (1961).
2. R. Forman, J. A. Ghormley, J. Appl. Phys. 33, 3057 (1962).
3. R. Forman, J. A. Ghormley, J. R. Reiss, Phys. Rev. 128, 1493 (1962).
4. J. G. Brainerd, F. Koehler, H. J. Reich and L. F. Woodruff, Ultrahigh Frequency Techniques, (D. Van Nostrand Company, Inc., New York 1942), Page 191.



U-2118

Figure 1. Sketch of Thermionic Diode

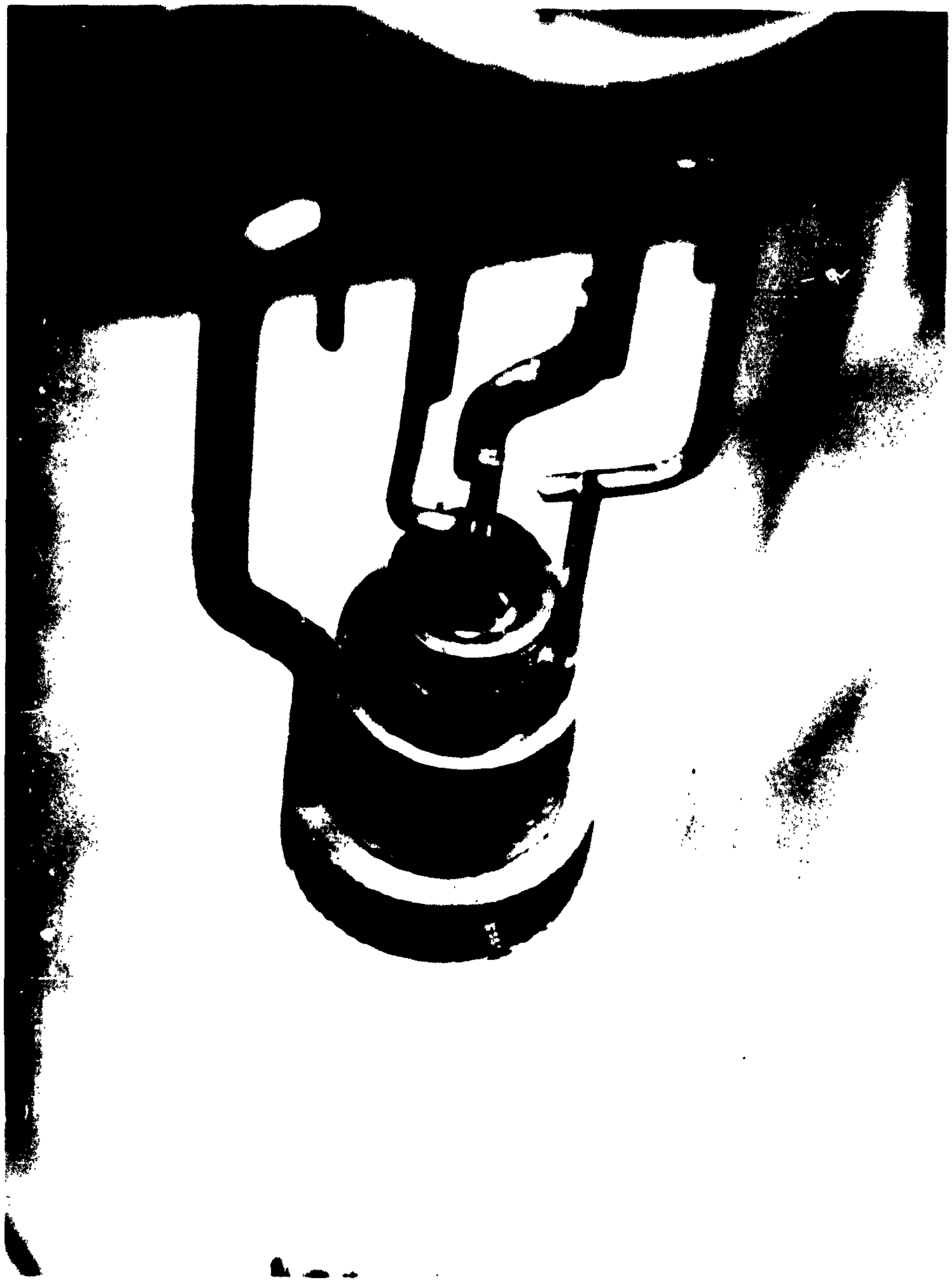


U-1984

Figure 2. Photograph of Thermionic Diode

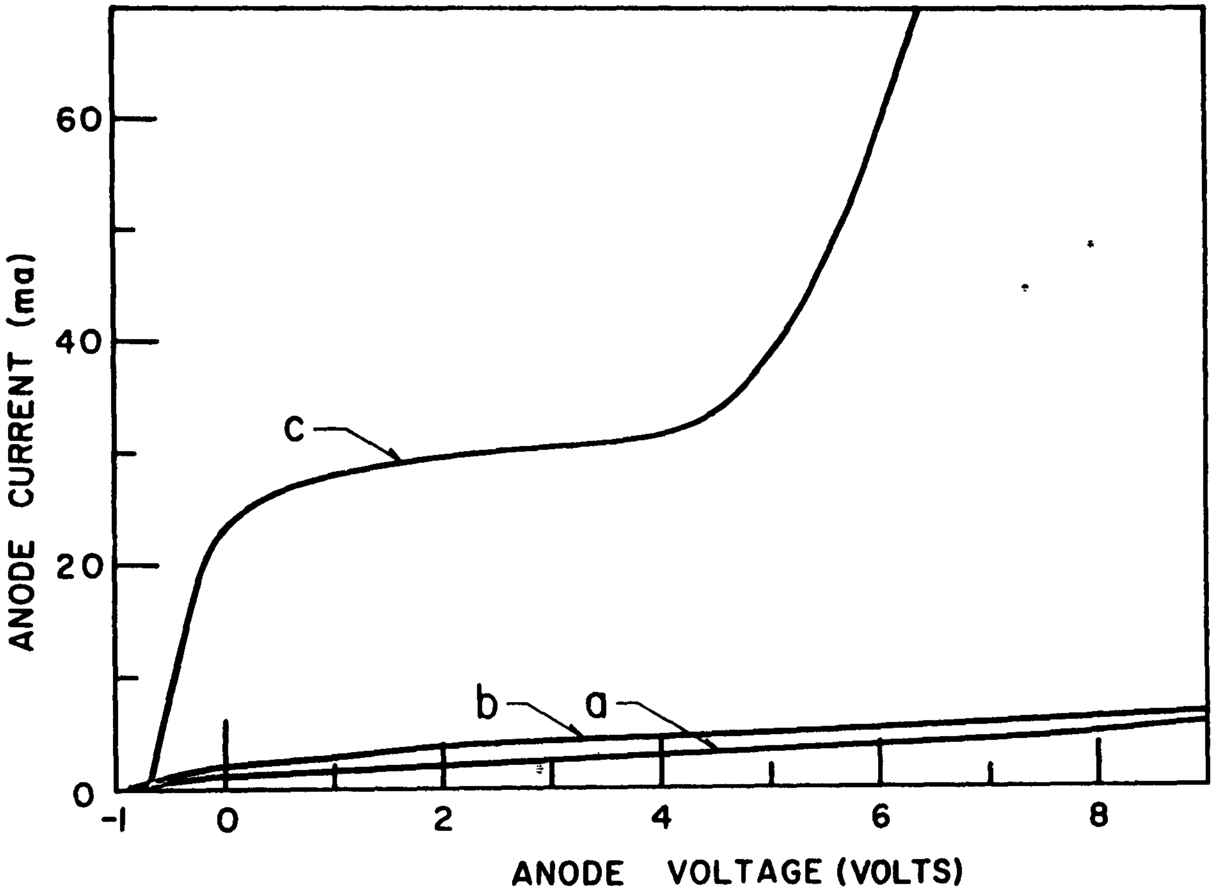
U-1986

Figure 3. Top View of Thermionic Diode



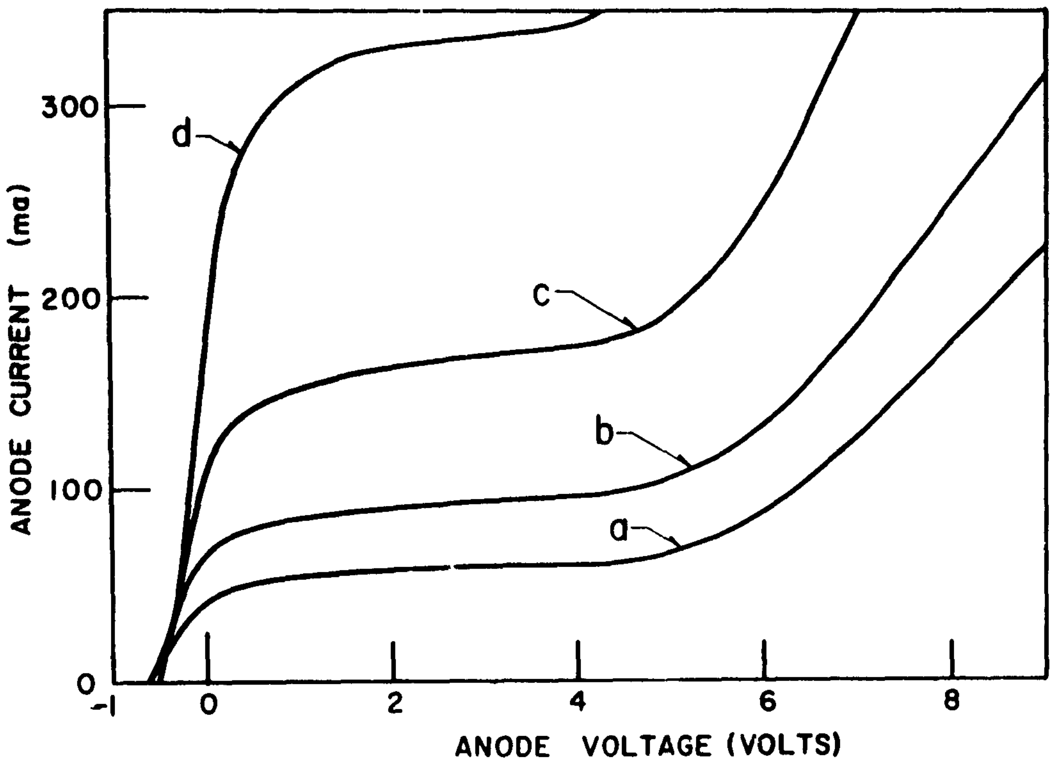
U-1985

Figure 4. Bottom View of Thermionic Diode



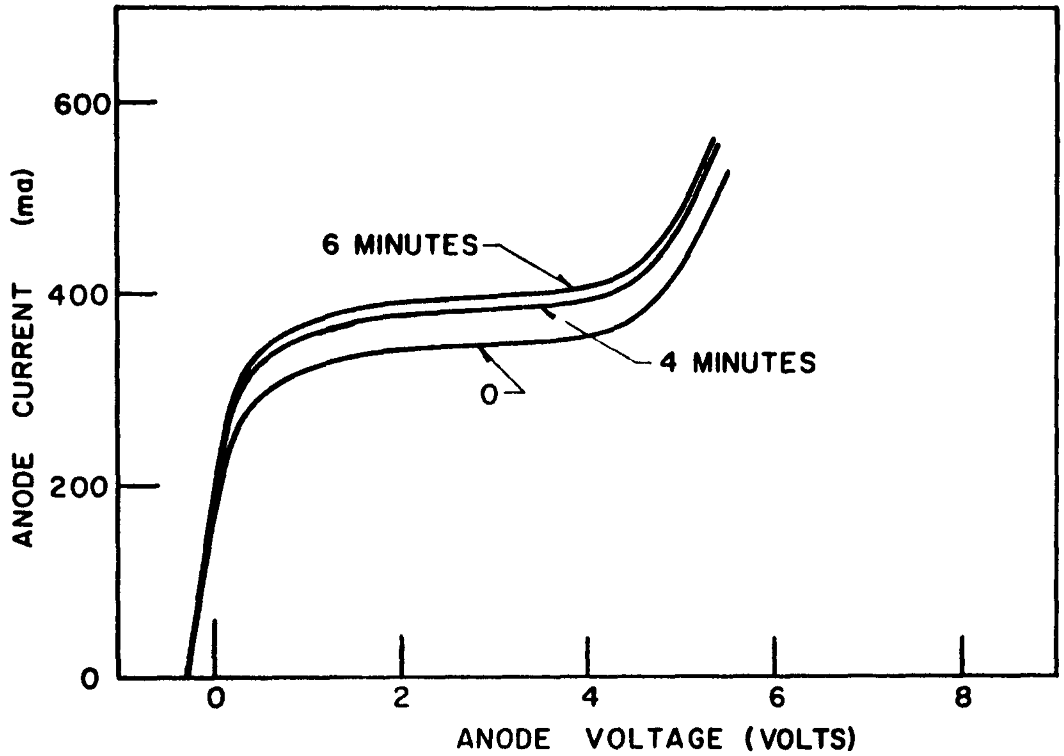
U-2120

Figure 5. Anode Current-Voltage Characteristics of an Argon Filled Diode as a Function of Irradiation (a) unirradiated (b) Co ^{60} irradiation (c) neutron reactor irradiation



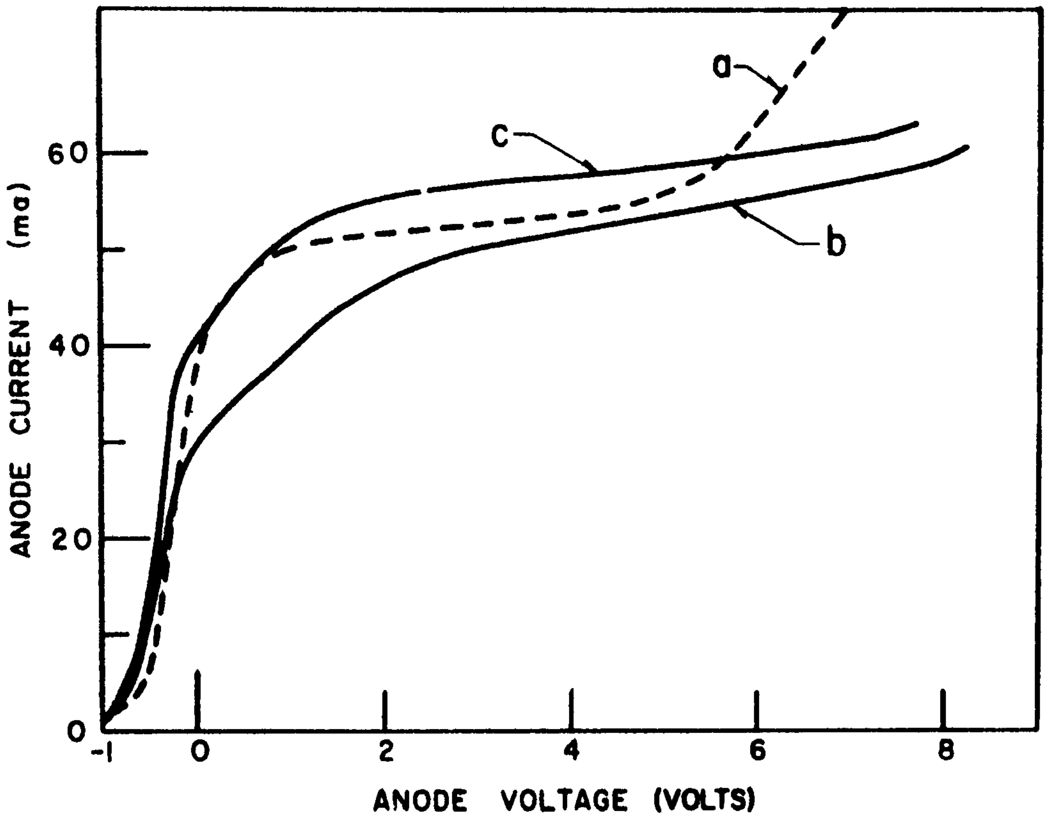
U-2122

Figure 6. Anode Current-Voltage Characteristics of an Argon Filled Diode as a Function of Irradiation The flux density in neutrons/cm^2 sec for the individual curves is (a) 5×10^{12} (b) 10^{13} (c) 2.5×10^{13} (d) 5×10^{13}



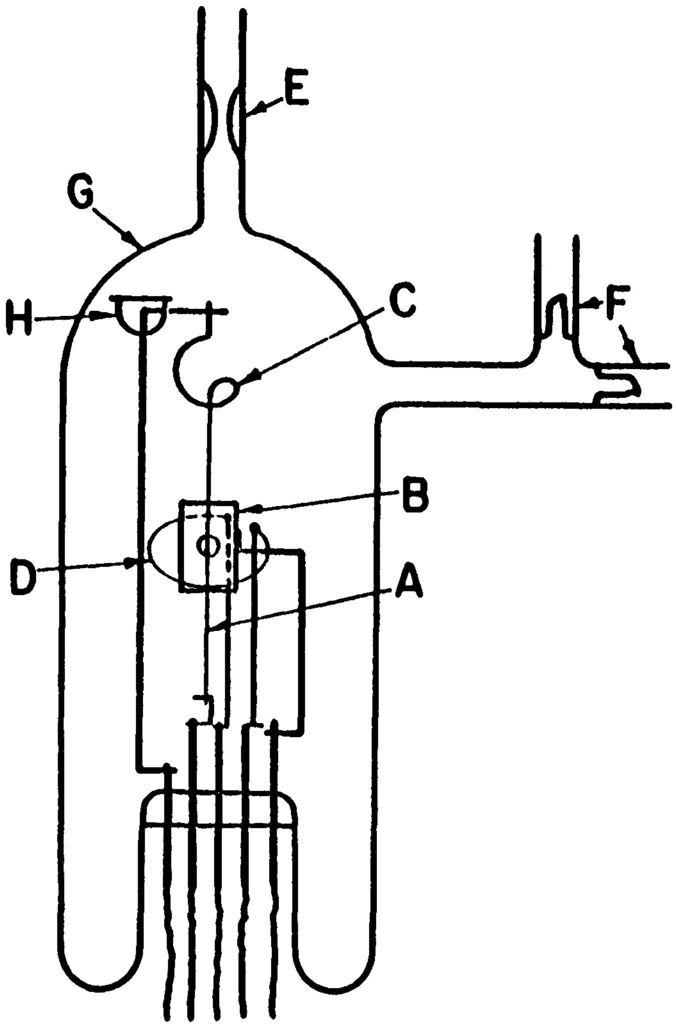
U-2121

Figure 7. Anode Current-Voltage Characteristics of an Argon Filled Diode as a Function of Time Under High Nuclear Radiation



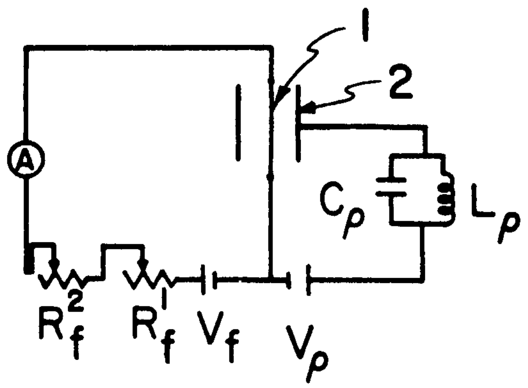
U-2117

Figure 8. Anode Current-Voltage Characteristics of a Krypton Filled Irradiated Diode as a Function of Cathode-Anode Spacing
(a) 1 mm (b) 3 mm (c) 7.5 mm

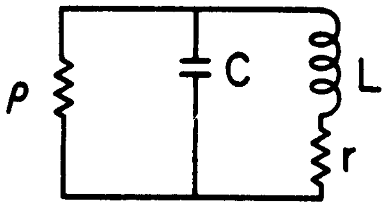


U- 2124

Figure 9. Fission Product Krypton Filled Thermionic Diode - A is a filamentary cathode, B is an anode, C is a filament spring support, D is an anode degassing filament, E is a seal-off joint and F are break seals for handling and removing fission product krypton from the diode. G is a Pyrex envelope and H is a "Kemet" barium getter.



(a)



(b)

U-2116

Figure 10. (a) Actual Negative Resistance Oscillator Circuit (b) Equivalent Circuit